REMARKS

In the Office Action dated April 7, 2004, the Examiner objects to the drawings and rejects claims 1-18, 20 and 21 under 35 U.S.C. § 103(a). The Examiner allows claim 19. After entry of this Amendment, claims 1-24 are pending in the application. Claims 1, 12 and 19-21 have been amended, and claims 22-24 have been added. Reconsideration of the Application as amended is respectfully requested.

With this Amendment, the Applicants have corrected a number of errors in the specification. The Substitute Specification filed herewith includes no new subject matter, but has been amended to correct minor typographical and grammatical errors. A redline/strikeout version of the Substitute Specification is also attached that shows the changes that have been made to the original specification as required by Section 608.01(Q) and 714.20(1) of the Manual of Patent Examining Procedure. Entry of the Substitute Specification is respectfully requested.

In the Abstract, a number of typographical errors have been corrected. Approval of the changes to the Abstract is respectfully requested.

OBJECTION TO THE DRAWING FIGURES

The Examiner objects to Fig. 6 because "morphology" is misspelled in element 56. Attached hereto is a replacement sheet including Fig. 6 with this error corrected and with the correct spelling of "Subtract" in box 44. In addition, "Yes" and "No" labels have been added to the arrows from queries 48 and 58. Support for these changes is found in paragraphs [0022]-[0023] and [0024], respectively. Grammatical errors have been corrected in boxes 40, 42 and 58. Finally, a correct reference to Image 1 has been made in box 44. Support for this change is found in paragraph [0021].

The Applicants have also attached a replacement sheet including revised Figs. 3 and 3A. In each of these Figures, element 24 has been correctly labeled as glint 28, and element 26 has been correctly labeled as shadow 30. Support for these changes is found in paragraph [0019].

Finally, the Applicants have attached a replacement sheet including Figs. 4 and 5.

In Fig. 4, element 24 has been correctly labeled as glint 28, and a line and reference number to the glint 24 has been added. In addition, the label for element 26 has been removed. Support for these changes is found in paragraph [0021].

REJECTIONS UNDER 35 U.S.C. §103

The Examiner rejects claims 1, 2 and 5-11 under 35 U.S.C. § 103(a) as being unpatentable over Nichani et al. (5,949,901) in view of Bartulovic et al. (6,177,682). The Examiner states that Nichani et al. teaches all the features of independent claim 1 except that Nichani et al. is silent about specific details of determining "the quantity of pixel characteristic of three dimensional features." The Examiner cites Bartulovic et al. as disclosing a method and apparatus for the inspection of BGA's to determine if the BGA's or similar structures meet certain predefined parameters and states that it would have been obvious to one of ordinary skill in the art at the time the invention was made to include specific details of determining the quantity of pixels characteristic of three dimensional features (which teaching is implied as being in Bartulovic et al.) in order to perform sophisticated and fast analysis on the BGA and to produce a three dimensional image of the BGA as suggested by Bartulovic et al. In claim 1, minor corrections of typographical errors have been made.

It is respectfully submitted that the Examiner has failed to make a *prima facie* case of obviousness with respect to claim 1 and its dependent claims. The Examiner is incorrect in stating that Nichani et al. teaches the steps of processing the third image to determine the quantity of pixels characteristic of three dimensional features therein and rejecting the substrate if the quantity of pixels characteristic of three dimensional features exceeds a predetermined threshold. In fact, Nichani et al. does not determine the quantity of pixels characteristic of three dimensional features therein and does not reject the substrate if the quantity of pixels characteristic of three dimensional features exceeds a predetermined threshold. The sections of Nichani et al. cited by the Examiner refer to the steps of normalizing the images, generating a difference image, mapping the difference image and performing morphology on the difference image. None of these steps in Nichani et al. involve the processing and rejecting steps described in claim 1.

Further, the addition to Bartulovic et al. in combination with Nichani et al., which in any case is not taught or suggested by the prior art, does not cure this deficiency because Bartulovic et al. also fails to teach or suggest the claimed steps. The quantity of pixels characteristic of three dimensional features in Bartulovic et al. is irrelevant to its purposes, which are to measure the coplanarity (relative heights), colinearity (alignment) and the height of each individual ball of the solder balls in a ball grid array (BGA). (Col. 1, ll. 17-20). Although Bartulovic et al. states that changing the illumination angle can help more precisely examine irregularities and defects of the ball shape close to its top, Bartulovic et al. contains no description of how this is done. (Col. 7, ll. 30-38).

For the foregoing reasons, claim 1 and its dependent claims 2-11 are allowable over the prior art of record.

In addition to the foregoing, it is respectfully submitted that claim 5 is allowable over the Examiner's proposed combination. That combination fails to teach or suggest the feature of claim 5 wherein the pixel addresses of all pixels in the third image which are above the threshold are recorded. In Nichani et al., the pixel addresses are irrelevant and are not recorded for any purpose. The addition of Bartulovic et al. in the Examiner's combination also fails to teach or suggest the feature because Bartulovic et al. does not contain the feature. Thus, claim 5 is allowable as containing patentable subject matter in addition to its allowability based upon its dependence from claim 1.

The Examiner states that the method of Nichani et al. includes the features of claim 6, which depends from claim 5. In addition to its dependence on claims 1 and 5, which are allowable, it is respectfully submitted that the Examiner's combination fails to teach or suggest the steps of claim 6 of selecting the minimum pixel value between the first and second images on a pixel address by pixel address basis to create a fourth image; and processing the fourth image, at and around the recorded pixel addresses, and rejecting the substrate if the processing falls outside predetermined tolerances. In Nichani et al., a first image and a second image are created and then a third image is created by subtracting the second image from the first image. (Col. 6, ll. 31-37). Optionally, a threshold image is created by mapping the second image, and the threshold image is

subtracted from the third image with the differences being mapped to one (1) or zero (0). (Col. 6, line 66 to col. 7, line 8). None of these images are created by selecting the minimum pixel value between the first and second images on a pixel address by pixel address basis as described in claim 6. For the foregoing reasons, the invention of claim 6 is patentable over the prior art of record.

The Examiner has failed to indicate which image of Nichani et al. is equated with the fourth image of claim 6. Indeed, the Examiner cannot because there is no image created as described in claim 6. However, neither the threshold image nor the mapped image described above are processed with gray scale morphology. Therefore, the cited combination also fails to teach or suggest the feature of claim 7 wherein the fourth image is processed with gray scale morphology.

In addition to its dependence from several allowable claims, it is respectfully submitted that claim 8 is allowable over the prior art of record. The Examiner states that Nichani et al. discloses a method for evaluating a substrate wherein the substrate is ceramic. However, Nichani et al. describes the substrate as silicon. (Col. 1, line 35). Ceramic or plastic are described only as packaging materials after a semiconductor die and its frame are assembled. (Col. 1, ll. 48-50). Nowhere does the cited combination teach a method wherein the substrate is ceramic as described in claim 8.

The Examiner states that Bartulovic et al. teaches the feature of claim 11 wherein the three dimensional feature is manifested as a glint, making the assumption that reflection off the substrate is considered to be glint. It is respectfully submitted that the Examiner has ignored the meaning of glint as described in the Applicants' specification. As described therein in paragraph [0018], a glint defines an area of locally higher gray-scale values. In the typical case, a glint will result in enough light to result in a gray-scale value of 255. Furthermore, even if the Examiner's assumption that a glint were a reflection off of the substrate were correct, which it is not, it would not be the manifestation of a three dimensional feature. Thus, claim 11 is allowable over the prior art of record.

The Examiner rejects claims 12-18 and 21 under 35 U.S.C. § 103(a) as being unpatentable over Nichani et al. (5,949,901) in view of Bartulovic et al. (6,177,682). Claim 12

has been amended to correct a typographical error, and claim 21 has been revised to depend from claim 19. The Examiner, in rejecting claim 12, refers the Applicants to the rejection of claim 1. However, claim 12 has different features from claim 1, and the Examiner has failed to identify where in any of the cited references the features of claim 12 are found. In fact, the cited references fail to teach several features of claim 12 and its dependent claims.

As mentioned previously, the Examiner has not used the appropriate definition of the word glints. Using the correct definition, it is clear that the cited references fail to teach or suggest the features of claim 12. Among other features of claim 12, the proposed combination fails to teach or suggest the feature of a processor configured to calculate the difference between the pixel values in the first image and the second image on a pixel address by pixel address basis to form a third image and the processor further configured to calculate the number of pixel addresses in the third image which are characteristic of three dimensional features. As mentioned with respect to claim 1, neither Nichani et al. nor Bartulovic et al. include this feature. The number of pixel addresses is irrelevant to both references. Thus, claim 12 and its dependent claims 13-18 are allowable over the prior art of record.

With respect to dependent claim 14, the proposed combination fails to teach or suggest the feature therein where the processor records the pixel addresses of the non-zero pixel values in the third image for the reasons set forth with respect to claim 5 described above. Thus, claim 14 is allowable both by dependency and based upon the recited feature therein.

Claim 15 includes the feature wherein the processor selects the minimum pixel value between the first and second images on a pixel address basis to create a fourth image, and the processor is configured to evaluate the size and concentration of the pixel values at the recorded locations, within the fourth image, the processor indicating that the substrate is rejected if the size and concentration of the three dimensional data exceeds predetermined tolerances. Claim 16 depends from claim 15 and includes the feature that the processor utilizes gray scale morphology to determine the size and concentration of the three dimensional features within the fourth image. It is submitted that the Examiner's combination fails to teach or suggest these features for the reasons set forth respectively for claims 6 and 7 above.

The Examiner rejects claim 3, 4 and 20 under 35 U.S.C. § 103(a) as being unpatentable over Nichani et al. in view of Bartulovic et al. and further in view of King et al. (5,943,125). Claim 20 has been amended to depend from claim 19 and is discussed in more detail hereinafter. It is respectfully submitted that there is no motivation to make the combinations suggested by the Examiner. As mentioned above, the prior art does not provide a motivation to combine Nichani et al. with Bartulovic et al. This is because Nichani et al. is directed to the detection of errors on a silicon die surface , while Bartulovic et al. is directed to the measurement of the coplanarity, colinearity and the height of individual solder balls in a ball grid array (BGA). (Col. 1, ll. 17-20). Similarly, King et al. is directed to the use of a ring illumination apparatus to examine protruding reflective elements such as solder balls. (Abstract; col. 4, ll. 32-41). These disparate inspection technologies have different needs and goals, and the only motivation to combine them is impermissible hindsight. The Examiner's combination, in any case, fails to teach or suggest all the features of claim 1 from which claims 3 and 4 depend.

In addition, it is respectfully submitted that the Applicants are unable to find anywhere in King et al. that teaches or suggests the described features in claims 3 and 4. The Examiner's citations to King et al. fail to show the feature of claim 3 wherein the threshold is set by a user. Nor does King et al. teach or suggest that the quantity of pixels characteristic of three dimensional data is determined by counting the pixel values which exceed the threshold. In fact, in King et al. groups of pixels are located, then the number of groups of pixels are counted. The actual number of pixel values is not used. (Col. 10, ll. 40-50).

ALLOWED CLAIM

With this Amendment, claim 19 is allowed. In claim 19, a minor typographical error has been corrected. As mentioned above, claims 20 and 21 have been amended to depend from claim 19. Claim 21 has been additionally amended to state that the processor is configured to apply gray scale morphology to the fourth image as described in the specification. It is respectfully submitted that claims 20 and 21 are also allowable over the prior art of record.

NEW CLAIMS

With this Amendment, new claims 22 to 24 have been added to claim a unique feature disclosed in the specification but not previously claimed. Claim 22 expands the subtracting step of claim 1, stating that the subtracting step further comprises subtracting the pixel values from the first image from the pixel values in the second image on a pixel address by pixel address basis and using an absolute value of each resulting pixel value to create the third image. Claim 23 depends from claim 12 and claim 24 depends from claim 19, and each adds the feature wherein the processor is further configured to calculate the difference between the pixel values in the first image and the second image on a pixel address by pixel address basis and to take an absolute value of the difference on a pixel address by pixel address basis to form the third image. Consideration of the new claims is respectfully requested. It is respectfully submitted that claims 22-24 are allowable over the prior art of record.

CONCLUSION

It is respectfully submitted that this Amendment traverses and overcomes all of the Examiner's objections and rejections to the application as originally filed. It is further submitted that this Amendment has antecedent basis in the application as originally filed, including the specification, claims and drawings, and that this Amendment does not add any new subject matter to the application. Reconsideration of the application as amended is requested. It is respectfully submitted that this Amendment places the application in suitable condition for allowance; notice of which is requested.

If the Examiner feels that prosecution of the present application can be expedited by way of an Examiner's amendment, the Examiner is invited to contact the Applicants' attorney at the telephone number listed below.

Respectfully submitted,

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SUBSTITUTE SPECIFICATION

DIRECTIONAL LIGHTING AND METHOD TO DISTINGUISH THREE DIMENSIONAL INFORMATION

~~FIELD OF THE INVENTION~~CO-PENDING APPLICATION

[0000.1] This application claims the benefit of the priority date of co-pending Provisional Application Serial No. 60/200,776, filed April 28, 2000 in the names of Kenneth Chapman and Sam Duhan, the entire contents of which ~~are~~is incorporated herein by reference.

FIELD OF THE INVENTION

[0001] The present invention relates to inspecting the surface of surface- mounted components for three-dimensional data.

BACKGROUND OF THE INVENTION

[0002] Surface-mounted components are inspected at many stages of their manufacture and for many different flaws. One type of component is a surface-mounted multi-layered ceramic capacitor (MLCC) component. As they are manufactured and used these components must be smooth, or planar. These components are typically made from ceramic and thus can be comparatively easily scratched, chipped or broken. These types of defects are generally referred to as three-dimensional, or 3-D defects. Ceramic components may also include other types of 3-D defects such as holes.

[0003] A core problem with inspecting ceramic components for 3-D defects is that it is difficult to distinguish between an unacceptable 3-D defect and an acceptable stain. To solve this problem the prior art developed highly sophisticated vision algorithms. Because a certain amount of imperfection can be tolerated, the algorithms must also qualify the 3-D defects as to whether they compel the rejection of a component or whether they can be tolerated. These algorithms did not operate as quickly as many manufacturers would have liked because of the amount of computer

processor time they required. Further, the prior art algorithms required that the components move at a comparatively slow~~er~~ rate so that the inspection could be carried out. The prior art
techniques often resulted in an artificially high rejection rate as vision algorithms could not distinguish between discolorations and 3-D defects.

[0004] Therefore a need has arisen to provide an inspection system ~~which~~ that can easily distinguish 3-D information from 2-D information at a comparatively faster rate without the use of excessive computational power.

SUMMARY OF THE INVENTION

[0005] The present invention provides a method and apparatus for cost effectively evaluating three-dimensional features on a substrate.

[0006] One aspect of the method of the present invention provides for evaluating three-dimensional features on a substrate including illuminating the substrate from a first angle and capturing a first image of the substrate. The first image is made up of a plurality of pixels, the pixels having an address~~,~~ and a value. The pixel address corresponds to a location on the substrate. The method also provides for illuminating the substrate from a second angle and capturing a second image of the substrate. The second image is also made up of a plurality of pixels where the pixels are addressed in the same manner as the pixels in the first image. Each pixel in the second image also has a value. The pixel values from the first image are subtracted from the pixel values in the second image on a pixel address by pixel address basis to create a third image. The third image is processed to determine the quantity of pixels characteristic of three-dimensional features therein. The substrate is rejected if the quantity pixels characteristic of three dimensional features exceeds a predetermined value.

[0007] A further aspect of the method of the present invention involves applying a threshold to the third image such that the pixel values are either zero or above the threshold. The non-zero pixel values are characteristic of three-dimensional features on the substrate. The pixel addresses corresponding to the non-zero pixel values may then be recorded. The

method may provide for creation of a fourth image by selecting the minimum pixel value between the first and second images on a pixel address by pixel address basis. Then the fourth image may be processed at the recorded pixel addresses to evaluate the pixel values at the recorded locations. The substrate may be rejected if the evaluation of the pixel values is outside defined tolerances.

[0008] Another aspect of the present invention provides an apparatus for evaluating three-dimensional features on a surface of a substrate. The apparatus includes a first light source positioned at a low angle relative to the substrate such that when the first light source illuminates the surface of the substrate, three-dimensional features on the surface of the substrate, having a first orientation, produce glints. A second light source is provided where the second light source is positioned opposite from the first light source~~,~~ such that when the second light source illuminates the surface of the substrate, three-dimensional features on the surface of the substrate, having a second orientation, produce glints. A camera is positioned perpendicularly above the substrate and the camera captures images of the substrate. The images are made up of a plurality of pixels, the pixels including an address characteristic of a location on the surface of the substrate and a value. The camera captures a first image of the substrate when the substrate is illuminated by the first light source, and the camera captures a second image of the substrate when the substrate is illuminated by the second light source. A processor is provided where the processor is configured to calculate the difference between the pixel values in the first image and the pixel values in the second image on a pixel address-by-pixel address basis to form a third image. The processor is further configured to count the number of pixel addresses in the third image ~~which~~that are characteristic of three-dimensional features.

[0009] According to a further aspect of the apparatus of the present invention, the processor applies a threshold to the third image such that the pixel values in the third image are either zero or above the threshold. The

pixel values ~~which~~that exceed the threshold are characteristic of three-dimensional features. The processor is operative in counting the non-zero values within the third image and indicating that the substrate is rejected if the number of non-zero pixel values exceeds a predetermined value.

[0010] According to a further aspect of the apparatus of the present invention the processor records the pixel addresses of those pixel values in the in the third image ~~which~~that exceed the threshold. The processor then selects the minimum pixel value between the first and second images on a pixel address basis to create a fourth image. The processor is configured to evaluate the pixel values in the fourth image at and around the recorded locations. The processor rejects the substrate if the evaluation of the pixel values at and around the recorded addresses fall outside defined tolerances.

[0011] Other applications of the present invention will become apparent to those skilled in the art when the following description of the best mode contemplated for practicing the invention is read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views~~,~~ and wherein:

FIGURE 1 is a schematic representation of the vision system of the present invention;

FIGURE 2 illustrates the present invention using a first light source;

FIGURE 2A is an image captured using the first light source;

FIGURE 3 illustrates the present invention using a second light source;

FIGURE 3A is an image captured using the second light source;

FIGURE 4 is a third image created by taking the absolute value between FIGURES 2A and 3A~~.~~;

FIGURE 5 is a fourth image created by taking the minimum value between FIGURES 2A and 3A~~.~~; and

FIGURE 6 is a flow chart illustrating the process of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0013] The present invention uses directional lighting to highlight 3-D regions in an image. In particular, the present invention captures two images of a substrate, typically made from ceramic, with low~~-~~ angled lighting positioned at opposite ends of the component. The images are subtracted from one another such that the 3-D regions on the component are identified. The 3-D regions are found in the subtracted image to further evaluate the 3-D regions.

[0014] Additionally, the system may record the locations at which the recorded locations may be used to process a minimum image when the minimum image is made up of the minimum values between the two captured images. The substrate may be rejected based on the salvation of the minimum image.

[0015] With reference to the figures~~, wherein like elements are numbered alike,~~ and in particular to FIGURE 1, there is shown a vision system **10**. Substrate **22** is typically ceramic, but it is understood that the present invention is not limited to the inspection of any particular substrate. Typically vision systems inspect components fairly comprehensively. That is, as described in the background of the invention, they inspect components for overall size, etc. Such inspection may also include measurement of the length of the termination band. The present invention is directed to 3-D features or defects including~~,~~ but not limited to~~,~~ scratches and cracks.

[0016] ~~Vision~~The vision system **10** includes a camera **12** positioned perpendicularly above a substrate **22**. Camera **12** preferably captures an eight bit gray-scale image having 256 different shades of gray, valued between 0 and 255. The images output from camera **12** are made up of a pixels. Each pixel has an ~~added~~address and a value~~-t~~. The address of the pixel is characteristic of a location on the surface of the substrate. The value of a pixel is the gray-scale value. In the preferred embodiment a CCD camera is used having an array of 640 x 480 pixels ~~and are~~which is available for purchase from Opteon. It is recognized that any other type of digital camera may be used, such as a CMOS sensor. Data from camera **12**, which represents an image of the substrate 22, ~~15~~is output to an image processor **14**. Image processor **14** processes the data as described below to accept or reject the component based on evaluation of pixel data characteristic of the 3-D factors. The image processor **14** preferably is a personal computer (PC).

[0017] In the first preferred embodiment, two light sources~~,~~ **16** and **18** are positioned at opposite ends of substrate **22**. In the preferred embodiment, light sources **16** and **18** are LED illuminators ~~which~~that can be controlled quickly such that each one illuminates sequentially. LED illumination is preferred because it is a rapid illumination technique, but it is not monochromatic ~~as to~~such that it creates interference ~~affects~~effects. It is understood that other type of quick illumination could be used such as strobe illumination.

[0018] With reference to FIGURES 2 and 3, as well at the flow chart illustrated at FIGURE 6 vision system **10** captures two distinct images of substrate **22**, at **40** and **42**. Each image is captured by camera **12**. As shown in FIGURES 2 and 2A the first image, or ~~image~~IMAGE 1 is captured using illumination from light source **16**. Similarly as shown in FIGURES 3 and 3A and the second image, or ~~image~~IMAGE 2 is captured using illumination from light source **18**. As shown in FIGURES 1~~,~~ and 2, when

~~image~~IMAGE 1 is captured with light source **16**, a 3-D feature **20** will produce a glint **24** on the side of the feature **20** distal from light source **16**, and ~~a~~the feature **20** will produce a shadow **26** on the side of defect **20** proximate to light **16**. As captured by camera **12**~~,~~ and illustrated by FIGURE 2A, glint **24** will result in~~ a~~ locally higher gray-scale values, and shadow **26** will result in locally lower gray-scale values. In the typical~~ly~~ case, glint **24** will result in enough light to result in a gray-scale value of 255. ~~Image~~IMAGE 1, as captured by camera **12** includes a plurality of pixels where the pixels have an address ~~of~~and a value. The address is characteristic of a location on the substrate.

[0019] As illustrated in FIGURE 3 and 3A ~~image~~IMAGE 2 is captured using illumination from light source **18**. As captured with light source **18**, a glint **28** appears where the shadow **26** had been in ~~image~~IMAGE 1 and a shadow **30** appears ~~were~~where the glint **24** had been. FIGURE 3A represents ~~image~~IMAGE 2. ~~Image~~IMAGE 2 is made up of the same number of pixels as ~~image~~IMAGE 1 and includes the same address scheme although ~~image~~IMAGE 2 includes different pixel values compared to ~~image~~IMAGE 1.

[0020] As shown in FIGURES 1, 2 and 3, light sources **16** and **18** are positioned at a low angle relative to substrate **22**. It is understood by those of ordinary skill in the art that a smaller angle from the horizon will yield more 3-D data (as described below)~~, h~~. However, as the angle from the horizon decreases the resulting images will be dimmer. It is also understood that as the light source is positioned at a higher angle from the horizon the image is brighter but the amount of 3-D data (as described below) decreases. It has been discovered that the preferred angle is between about ten degrees and fifteen degrees from the horizon. Positioning the light sources at this angle results in the optimum creation of glints and shadows for a wide range of 3-D defects.

[0021] With reference to FIGURE 6 there is shown a flow chart describing, in its majority, the operation of image processor **14**. As shown

~~image,~~ IMAGE 1 and ~~image~~IMAGE 2 are captured at **40** and **42**. As shown at **44** the pixel values from ~~image~~IMAGE 1 are subtracted from the pixel values ~~image~~from IMAGE 2 on a pixel address-by-pixel ~~location~~address basis. Thus, for 3-D data, glints are subtracted from shadows and shadows are subtracted from glints, each resulting in a comparatively high or bright value. For 2-D data the pixel values for any given pixel location in either of ~~image~~IMAGE 1 or ~~image~~IMAGE 2 will be the same~~ and if~~ not close to the same. Thus, subtracting ~~image~~IMAGE 1 from ~~image~~IMAGE 2 for 2-D data will result in values of zero, or not much greater. ~~Image~~IMAGE 3 is created as the absolute value between the difference between ~~image~~IMAGE 1 and ~~image~~IMAGE 2.~~-~~ FIGURE 4 illustrates the absolute value between the difference between ~~image~~IMAGE 1 and ~~image~~IMAGE 2 where the background is black and both glints are illustrated.

[0022] As shown at **46**, image processor **14** applies a threshold to ~~image~~IMAGE 3 to eliminate artifacts. Thresholding an image is well known in the image processing field. Application of a threshold will yield pixel values ~~which~~that are zero or above the threshold. After a threshold has been applied to ~~image~~IMAGE 3, the image processor **14** can determine the magnitude of 3-D data by simply counting the number of pixel~~s~~ locations ~~which~~that have a non-zero value. If the number of ~~pixels~~pixel locations having a non-zero value exceeds another threshold at **48**, the part is rejected as having an excess of 3-D data a~~nd~~t **50**. For purposes of the comparison at **48** the quality, or shape, of the 3-D defects ~~are~~is not evaluated. The threshold at **48** is based on the simple premise that if there is an excess of 3-D data~~,~~ at least some of that data must represent fatal defects. Preferably this threshold is set by a user when the system is initially installed based on the user's individual requirements.

[0023] If the amount of 3-D data is not so great as to warrant rejecting the component at **48** and **50**, the system records the addresses at which the non-zero pixel values are located at **52**. ~~Image~~IMAGE 4 is created at **54**. ~~Image~~IMAGE 4 is created by comparing ~~image~~IMAGE 1 to ~~image~~IMAGE 2

and selecting the minimum pixel value for any given pixel address. This results in selecting the values representing the shadows as found in 3-D data from ~~image~~IMAGES 1 and 2. ~~Image~~IMAGE 4 is illustrated at FIGURE 5.

[0024] At **56**, the image processor **14** processes ~~image~~IMAGE 4 at and around those locations containing 3-D data as recorded at **52**, i.e., at and around the pixel addresses ~~which were~~ recorded at **52**. Because the locations of the 3-D features are known based on recordation at **58**, the image processor **14** can use standard morphology as recognized by those of skill in the art to access the shape and size of the 3-D feature. Such well-known techniques include gray-scale morphology. If the size and shape of the defect is acceptable, as defined by user set tolerances, the part is accepted relative to 3-D defects at **62**; if the size and shape is unacceptable then the component is discarded at **60**.

[0025] Morphology is used to eliminate any very small regions, leaving only those areas that are of a size large enough to be considered a defect. If the region is a 3-D region and it is large enough then it is a defect even if the total 3-D pixel count is not large enough to trigger rejection at **50**. This may be the case where the morphology determines that the 3-D data is highly concentrated in a single area on the component. The morphology examines both the size of any individual 3-D defect (defined as a substantially contiguous area of 3-D data) as well as their concentration within a specific area. The basis for rejecting or accepting a component after determination of the size of the 3-D defect will depend on the specific component inspected as recognized by those of ordinary skill in the art.

[0026] The present invention allows components which include 3-D data below the initial threshold to be accepted as long as the contiguous regions of 3-D data are individually small.

[0027] While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to

the disclosed embodiments but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as is permitted under the law.

ABSTRACT OF THE DISCLOSURE

[0028] The present invention provides a method and an apparatus for evaluating the surfaces of substrates for three dimensional defects. The present invention uses low angled lighting positioned on opposite sides of the substrate. A camera, positioned above the substrate captures two images thereof, one using the first light source, and one using the second. The first and second images are subtracted from one another to create a third image. Camera data suggestive of three dimensional features is emphasized by subtracting the two images and can be evaluated. A fourth image may be created by selecting the minimum values between the first and second images on a point by point basis. The fourth image also provides useful information in evaluating three dimensional defects.